CREEP AND THERMAL RESPONSE OF LONG SPAN PRESTRESSED CONCRETE INTEGRAL ABUTMENT BRIDGE

AKILU MUHAMMAD

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Universiti Teknologi Malaysia

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ABSTRACT

Integral Abutment Bridges (IAB) are getting popular due to significant cost savings in their construction and maintenance. Many countries stipulate the use of IABs in their new bridge construction projects but mostly the span is limited to 60 m. The limit is set considering the concerns on the long-term performance of IAB beyond 60 m span due to complexities in its response to long-term material behaviour, environmental loading and backfill soil conditions. This limitation necessitates the need for research to adequately predict the long-term behaviour of IAB particularly those with span beyond 60 m. A parametric study is carried out by performing non-linear finite element analyses using LUSAS to determine the long-term behaviour of continuous span prestressed concrete IAB. The parameters considered are backfill soil type, bridge total length, thermal loading and creep. Subsoil behind bridge abutment is varied from dense sand, loose sand, stiff clay, to medium stiff clay. The bridge total lengths of 60 m, 90 m, 120 m, and 150 m, with pier-to-pier spans of 20 m, 30 m, 40 m and 50 m are considered respectively. Three dimensional models of IAB are subjected to self-weight, vehicle loading, prestressing force, temperature load ranging from 20 ^{0}C to 36 ^{0}C and concrete creep. The bridge response at 75 year life is examined in terms of deformations and changes in internal forces in the abutment, prestressed beams and pile foundations. The long term response of the IAB with different backfill soil types and span lengths subjected to all possible loadings was successfully quantified. The results revealed that the variation of the displacement and the internal forces in the abutment and the bridge beam are within the constructable limit where it is possible to design and construct the IAB beyond the length of 60 m. Seventy five years creep and shrinkage loading is found to have significant effect on long term behaviour of the bridge. It causes maximum loss in prestress force by 27 % resulting in reduced moment and shear capacity of girder by 557 kNm and 321 kN respectively and increases the girder deflection by 75 mm (160 %) in 150 m IAB. This also resulted in incremental abutment deflection 25 mm (575 % rise), abutment moment 5410 kNm (95 %), abutment shear 440 kN (41 %), and girder stress 7.53 N/mm^2 (378 %) in 150 m long IAB. Soil-abutment interaction is found to have predominant effect in comparison to soil-pile interaction. Bridge length has considerable effect on magnitude of abutment moment causing 5870 kNm (112 %) incremental moment with increase in bridge length from 60 m to 150 m in varying subsoil stiffnesses. Results of the analyses are used in the formulation of long-term response prediction equations for deflection, moment and shear behavior of IAB abutments. The empirical equations have proven to be adequate and time efficient means of predicting deformations and changes in internal forces in the IABs of similar geometry and configurations.

ABSTRAK

Pembinaan Jambatan Tembok Landas Bersepadu (IAB) semakin popular sekarang kerana ia memberikan penjimatan kos yang ketara daripada segi pembinaan dan penyelenggaraan. Banyak negara telah mensyaratkan pembinaan IAB bagi projek pembinaan jambatan yang baharu, namun panjang jambatan kebanyakannya dihadkan kepada 60 m sahaja. Pertimbangan untuk menghadkan panjang jambatan ini adalah berdasarkan kepada ketidaktentuan prestasi bahan konkrit dalam jangka panjang, ketidaktentuan beban yang terjana daripada persekitaran dan juga ketidaktentuan keadaan tanah tambun di belakang tembok landas. Kekangan ini menyebabkan perlunya dijalankan penyelidikan bagi membuat jangkaan kelakunan jangka panjang IAB, terutamanya bagi panjang keseluruhan yang melebihi 60m. Satu kajian parameter telah dijalankan dengan kaedah analisis unsur terhingga tidak lelurus menggunakan LUSAS bagi menentukan kelakunan jangka panjang jambatan IAB yang dibina dengan rasuk konkrit prategasan selanjar. Parameter yang diambil kira adalah jenis tanah tambun di belakang tembok landas, panjang keseluruhan jambatan, beban suhu dan rayapan konkrit. Jenis tanah tambun di belakang tembok landas diubah-ubah iaitu daripada jenis pasir tumpat, pasir gembur, tanah liat kukuh, kepada tanah liat sederhana kukuh. Panjang keseluruhan jambatan yang dipertimbangkan adalah 60 m, 90 m, 120 m, dan 150 m dengan jarak antara pier penyokong adalah masing-masing 20 m, 30 m, 40 m and 50 m. Model tiga dimensi bagi IAB dikenakan beban berat diri, beban kenderaan, daya prategasan, beban suhu dengan julat daripada 20 ^{0}C kepada 36 ^{0}C dan juga rayapan konkrit. Kelakunan jambatan pada umur 75 tahun telah diperiksa dengan melihat kepada nilai pesongan dan perubahan daya dalaman dalam tembok landas, dalam rasuk prategasan dan dalam asas cerucuk. Kelakunan jangka panjang IAB yang berinteraksi dengan pelbagai jenis tanah tambun dan panjang keseluruhan jambatan yang berbeza-beza di bawah semua jenis beban telah diperolehi dengan jayanya.. Hasil yang didapati adalah perubahan daya dalaman tembok landas dan rasuk prategasan bagi jambatan IAB yang melebihi 60m adalah dalam had yang boleh direkabentuk dan boleh dibina. Beban rayapan dan pengecutan selepas 75 tahun didapati memberi kesan yang besar ke atas kelakunan jangka panjang jambatan. Ia menyebabkan pengurangan daya prategasan maksimum sebanyak 27.1 % yang akhirnya mengurangkan kapasiti moment dan daya ricih rasuk masing-masing sebanyak 557 kNm dan 321 kN serta menambahkan pesongan rasuk sebanyak 75 mm (160 %) pada IAB 150 m panjang. Ia juga menghasilkan penambahan pesongan tembok landas sebanyak 25 mm (575 %), momen tembok landas sebanyak 5410 kNm (95 %), ricih tembok landas 440 kN (41 %) dan tegasan rasuk 7.53 N/mm^2 (378 %) pada IAB 150 m panjang. Tinda balas yang besar berlaku antara tanah-tembok landas tetapi tidak besar pada tanah-cerucuk. Panjang jambatan memberi kesan yang besar ke atas nilai momen tembok landas yang berinteraksi dengan kekukuhan tanah tambun yang berubah-ubah, iaitu pertambahan sebanyak 5870 kNm (112 %) apabila panjang jambatan bertambah daripada 60 m kepada 150 m. Hasil daripada analisis telah diguna untuk menerbitkan rumus bagi membuat ramalan kelakunan jangka panjang nilai pesongan, momen dan daya ricih tembok landas IAB. Rumus empirik ini terbukti menjadi kaedah yang memadai dan menjimatkan masa bagi membuat ramalan pesongan dan perubahan daya dalaman IAB yang sama bentuk dan ukuran.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

q	-	Reaction forces of foundation
w	-	deflection of the beam on elastic foundation
k	-	Modulus of subgrade reaction
p	-	Lateral soil resistance per unit length of pile
y	-	Lateral deflection of soil per unit length of pile
E_s	-	Soil modulus
P_u	-	Ultimate value of resistance of soil per unit length of pile.
γ	-	Unit weight of soil
Z_t	-	Wedge depth of soil
C_u	-	Undrained shear strength of clay
z	-	Depth of soil from ground level
P_{ult}	-	Ultimate soil resistance in cohesive soil
K_0	-	Coefficient of earth pressure at rest
K_a	-	Minimum coefficient of active earth pressure
α	-	Angle of wedge action along the horizontal direction
β_a	-	Angle of wedge action along the vertical direction
e	-	Void ratio of soil
p'	-	Mean confining stress less pore water pressure in the soil
p_{atm}	-	Atmospheric pressure
γ	-	Shear strain of soil
ρ_d	-	Dry density of soil
G_s	-	Specific gravity of soil
ρ_w	-	Density of water

δ	-	Distance moved by backfill due to abutment push
H	-	Height of the abutment
k_{horz}	-	Horizontal soil stiffness
t	-	Time
$\varepsilon_{cr}(t)$	-	Creep strain
$\varepsilon_{sh}(t)$	-	Drying or shrinkage strain.
$\varepsilon\ (t)$	-	Uncracked and uniaxially loaded concrete strain.
$\varepsilon_{e}(t)$	-	Instantaneous strain
$\varepsilon_{sh}(t)$	-	Shrinkage strain
$\varepsilon_{T}(t)$	-	Temperature strain
σ_{c0}	-	Concrete strain components under sustained compressive stress
τ_{0}	-	initial time
τ_{d}	-	Early shrinkage strain
τ_{0}	-	Instantaneous increase in strain.
τ_{1}	-	Time when instantaneous stress is removed
$\varepsilon_{cr.d}(t)$	-	Recoverable strain or delayed elastic strain
$\varepsilon_{cr.fi}(t)$	-	The first part is recoverable strain
$\varepsilon_{cr.fb}(t)$	-	Basic flow component of second part of recoverable strain
$\varepsilon_{cr.fd}(t)$	-	Drying component of second part of recoverable strain
$\varepsilon_{cr.f}(t)$	-	Irrecoverable part of the creep strain is called flow
P_{s}	-	Axial force due to differential shrinkage
ε_{s}	-	Unrestrained differential shrinkage
E_{sl}	-	Elastic modulus of slab
E_{b}	-	Elastic modulus of beam
A_{s}	-	Cross sectional area of slab
A_{b}	-	Cross sectional area of beam

M_s - Shrinkage moment

P_s - Horizontal shear force

e_s - Distance from top of beam to center of slab

y - Distance from beam neutral axis to top of beam

σ_c - Compressive strength

$\varepsilon_{ci}(t_0)$ - Initial strain at loading

$\varepsilon_{cc}(t)$ - Creep strain at time $t > t_0$

$\varepsilon_{cs}(t)$ - Shrinkage strain

$\varepsilon_{cT}(t)$ - Thermal strain

$\varepsilon_{c\sigma}(t)$ - Stress dependent strain

$\varepsilon_{cn}(t)$ - Stress independent strain

$J(t,t_0)$ - Creep function or creep compliance

$E_c(t_0)$ - Modulus of elasticity at the time of loading

β_{cct} - Coefficient that depends on the age of concrete

φ_0 - Notional creep coefficient

β_c - Coefficient to describe the development of creep with time after loading.

t_0 - Age of the concrete at loading

h - Notional size of the concrete member

A_c - Area of concrete cross section

u - Length of the perimeter of the concrete section

f_{cm} - mean concrete compressive strength

RH - Relative humidity of the ambient environment (%)

$a_i(\tau)$ - Creep compliance coefficients which is dependent on age of loading

G - Linear spring of stiffness

β_s	-	Coefficient to describe the development of shrinkage with time
t_s	-	Age of concrete at the beginning of shrinkage
ε_m	-	Incremental non-mechanical strain
ΔT_{Mheat}	-	Linear temperature difference component with for warmer top cooler bottom
ΔT_{Mcool}	-	Linear temperature difference component for cooler top warmer bottom
ΔT_E	-	Nonlinear temperature difference component
qz	-	Internal heat generated in the concrete
ρ	-	Density of concrete
c	-	Specific heat capacity of concrete
T	-	Temperature
k_c	-	Thermal conductivity of concrete
f_{pe}	-	Design effective prestress in tendon after all losses
f_{ps}	-	Calculated stress in prestressing steel at section considered and loading considered
f_{pu}	-	Characteristic strength of tendon
M_u	-	Ultimate moment capacity of prestressed concrete girders
ε_u	-	Maximum compressive strain of concrete
f_{cu}	-	Characteristic strength of concrete
γ_m	-	Material factor of safety of concrete
C	-	Compressional force in concrete
T	-	Tensional force in concrete
f_{pb}	-	Design tensile stress in tendons at beam failure
ε_{pb}	-	Ultimate strain in tendon at failure
A_{ps}	-	Area of prestressing steel

d	-	Effective depth of prestressed beam to centroid of tendons
b	-	Effective width of concrete beam
ε_{pb}	-	Ultimate strain in tendon
ε_{ce}	-	Effective prestrain in concrete
ε_{p}	-	Strain in tendon due to flexure
ε_{pe}	-	Effective prestrain in tendon
x	-	Depth of neutral axis
P_i	-	Prestress force
E_{ps}	-	Modulus of elasticity of tendon
I_{xx}	-	Moment of inertia of girder
e	-	Eccentricity of cable from neutral axis of girder
A_c	-	Area of concrete girder
E_c	-	Modulus of elasticity of concrete
β	-	Reduction factor for long term prestress loss
V_{co}	-	Ultimate shear resistance of prestressed concrete section
f_t	-	Allowable principal stress
b_v	-	Breadth of section or width of web for T, L and I sections
M_o	-	Moment that produces zero stress at extreme tension fiber.
f_{pt}	-	Level of prestress in concrete at tensile face.
v_c	-	designed concrete shear stress
M	-	Bending moment due to applied load
V	-	Shear force due to applied load
f_{cp}	-	Design stress at the end of prestress development length
l_p	-	Prestress development length
γ	-	Average shear strain of soil
ϕ	-	Angle of internal friction

y_u	-	Ultimate soil deflection
p_u	-	Ultimate soil resistance
C_u	-	Undrained cohesion of soil
y_{50}	-	Half of deflection of soil at ultimate soil resistance
ε_{50}	-	Strain corresponding to one-half the maximum deviator stresses in an undrained test
a	-	Nodal displacement
r_{ps}	-	Radius of curvature
μ	-	Duct friction coefficient
M_i	-	Moment due to self-weight of beam
ε_{sh}	-	Shrinkage of concrete per unit length for outdoor exposure
f_c	-	Stress at centroid of prestressing steel
K	-	Unintentional angular displacement for internal tendons
P_x	-	Tendon force at a distance from the beginning of the curve
P_{ie}	-	Tendon force at end of the curve
f_i	-	Initial stress at jacking
f_{st}	-	Characteristic strength of strand

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.2 Background of the Study

Bridges have been part of any country's infrastructural development. They connect road and rail networks with overpass over obstacles like large bodies of water, valleys, or existing roads. Their desirable characteristics include structural stability and durability, simplicity of construction, minimal maintenance, smooth riding surface, water tightness and aesthetics. Single or multi-span bridges are usually constructed with expansion joints to accommodate expansion and contraction of superstructure due to volumetric strains caused by thermal, creep and shrinkage stresses. Strains from temperature load can lead to cracks development on concrete which can result in early deterioration of concrete components. Expansion joints are therefore provided in jointed bridges to accommodate thermal expansions and contractions; bearings are also provided to accommodate superstructure movement arising from live loads as shown in Figure 1.1.

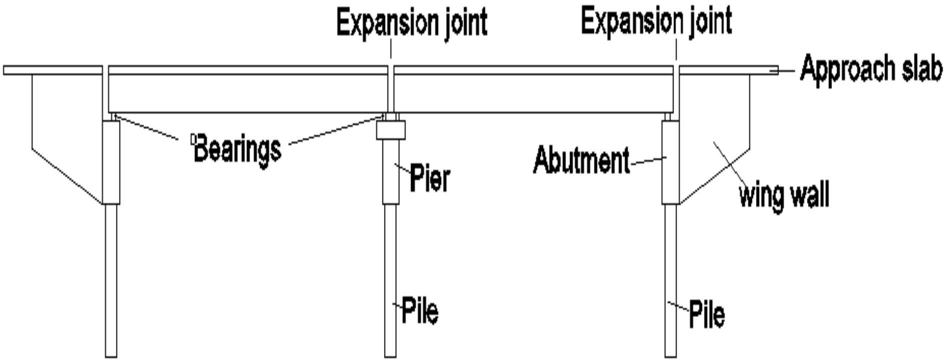

Figure 1.1 Scheme of a Jointed Bridge

Expansion joints come with their maintenance problems. They are costly to purchase and install and they wear with time from vehicular traction and environmental effects (Figures 1.2, 1.3, 1.4). This can result in rough driving surface, ingress of rain water and de-icing salts, freezing and thawing of trapped water in joints, leaking of joints and corrosion of reinforced concrete and bearings (Figure 1.5). Expansion joints and bearings were realised to be the major source of bridge maintenance problems; extensive and expensive replacement works that usually consumes a greater portion of bridge maintenance budget are carried out to repair faulty joints and bearings (Wolde-Tinsae et al., 1988; Mistry, 2005; Sophia et al., 2006). Leaking joints account for 70 % of defects occurring at ends of girders, piers and abutment seats (Rodolf and Samer, 2005). Maintenance of expansion joints and bearings, in many instances, result in disruption of traffic movement and intra and inter city economic activities.

Figure 1.2 Expansion joint failures (BadwaterJournal.com, 2011)

Figure 1.3 Dangerous expansion joint failures (Emseal Infrastructure & Civil Products, 2014)

Figure 1.4 Dangerous expansion joint failures (Harry, 2006)

Figure 1.5 Corrosion of bridge bearing (Michel et al., 2010)

Problems associated with expansion joints and bearings are eliminated with a different form of bridge construction that is gaining popularity today, known as Integral Abutment Bridge (IAB) or Joint-less Bridge. It is a single or continuous multi-span bridge that has no movable longitudinal deck joints at abutment and piers (Burke, 2009). In other words, it is a frame type structure having no movement joints and bearings (Figure. 1.6) where the superstructure and substructure are monolithically and rigidly connected. This makes the structure to act as a single unit with improved stiffness and rigidity. The superstructure movements from live load, temperature, and creep are transferred to the abutments. Dicleli (1999) also viewed IABs as single-span or multiple-span bridge that has a continuous deck and whose only mechanism of movement is abutment that is supported on flexible piles. This structural arrangement results in transferring the cyclic movement of the bridge superstructure to all substructure components. Consequently, soil-substructure interaction namely backfill-abutment and soil-pile foundation interaction affects the bridge movement and has been identified as the key factor influencing the behaviour of IABs (Faraji et al., 2001; Khodair, 2005). The stiffness of backfill provides resistance to longitudinal bridge movement due to thermal and breaking loads (British highway agency, 2003).

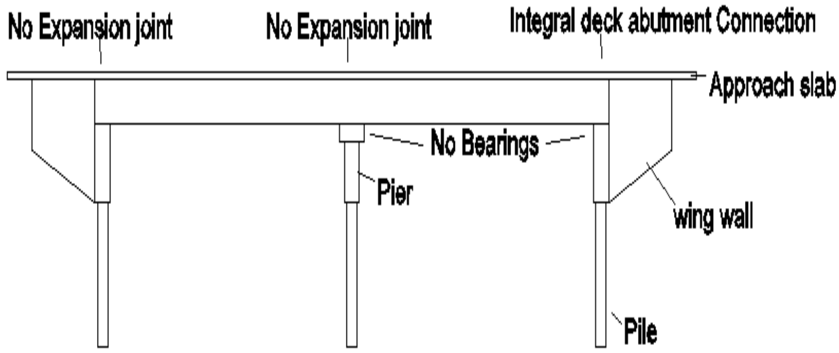

Figure 1.6 Scheme of an Integral Abutment Bridge

Integral connection of bridge superstructure and abutment in IAB eliminates the need for joints, bearings, and the cost for their maintenance. This system simplifies construction procedure and enhances structural performance of bridges as a result of the rigidity of superstructure-abutment connection. IABs have therefore become popular in many countries due to their functional and economic advantages. In UK and Ireland in particular, bridges not exceeding 60 m span and 30^0 skew are now required to be designed as IAB (O’brien and Keogh, 2005). Many transportation agencies in the US and Canada prefer the choice of IABs (Dicleli and Erhan, 2009).

1.3 Overview of Integral Abutment Bridge

Bridges constructed before the 20th century (1900) were Integral Abutment Bridges (IABs). As bridges span longer distances in 20th century, expansion joints or movement joints were introduced to accommodate thermal movement. Expansion joints are now gradually removed from bridge designs to reduce the high cost of maintenance thereby retuning back to earlier design pattern (Nicholson, 1998). Jointless bridges began to be developed on experimental basis, with short bridges ranging from 15 m to 30 m, during the 1930s in the United States, Australia and New Zealand. Due to the absence of rational design guides, bridge length was subsequently increased based empirically on successful performance of other bridges. This led different highway transport agencies developing their own design criteria and length limitations (Wolde-Tinsae et al., 1988).

In traditional highway bridges, movement joints and bearings are usually provided to allow structural movement due to thermal variation, creep and shrinkage (Arockiasamy et al., 2004). In the 1960s when traffic loads increased in volume, weight and speed, there was increased demand for maintenance of joints and bearings (Wolde-Tinsae et al., 1988). Maintenance and replacement works became more regular consuming a major share of bridge maintenance budget. Gradual deterioration of expansion joints form heavy impacts of bridge live loads, thermal expansions and contractions, creep, shrinkage contractions and foundation settlement leads to leakage of salt laden water form bridge surface to underneath of bridge deck, corroding bridge girder, bearings and reinforced concrete substructures. The problem is exacerbated in regions that experience heavy snow where de-icing chemicals like sodium chloride and calcium chloride are commonly used (Kier, 2009). The problem is magnified when the drainage troughs are not functioning properly due to accumulation of dirt. In addition to structural damage, leaky joints give unpleasant aesthetic appearance requiring regular cleaning and repainting. Studies have linked faulty expansion joints and/or the attendant maintenance operations to road accidents and hazardous roadway condition (Rabih Haj-Najib, 2002). Elastomeric glands also become filled with water and dirt leading to its eventual failure (Mistry, 2005). Different types of expansion joints are manufactured to accommodate varied types of movements, some with improved performance over others, but all expansion joints eventually fail with time leading to expensive repair and replacement works.

In view of the numerous problems associated with expansion joints, jointless bridges become an alternative to destructive effect of leaking and freezing deck joints (Burke, 1993). In addition to reduction in high cost of maintenance, construction process is simplified and construction cost is reduced with the removal of joints and bearings (Griemann et al.,, 1986; Hans and Peter, 2006). Studies by Hans (2015) have shown that significant savings in bridge construction costs is achieved with the use of IABs (Figure 1.7). IABs are therefore rapidly gaining popularity; many states in US have resorted to the removal of joints and associated bearings in the proposed and existing bridges to save cost (Figure 1.8). Kunin and Alampalli (1999) discovered that nearly 10,000 IABs were built by 30 bridge agencies in United States between 1969 and 1999. The number of Integral and Jointless Bridges (IAJB) comprising both integral and semi-integral abutment bridges (that has abutments-girder joints) amounted to 13,000 in U.S. according to survey conducted by Rodolf and Samer in 2005 (Table 1.1). In the ten years preceding the survey, US had a 200 % surge in number of IABs. Over 1000 IABs were built in Finland during recent decades (Olli et al., 2005). Figure 1.9 shows increase in use of IABs in UK within a four year period. Bridge maintenance costs of jointed bridges have been a source of concern for many bridge agencies. Experience from US, Sweden and many countries have shown that IABs are a better alternative due lower financial demand for their construction and maintenance (Feldmann et al., 2006).

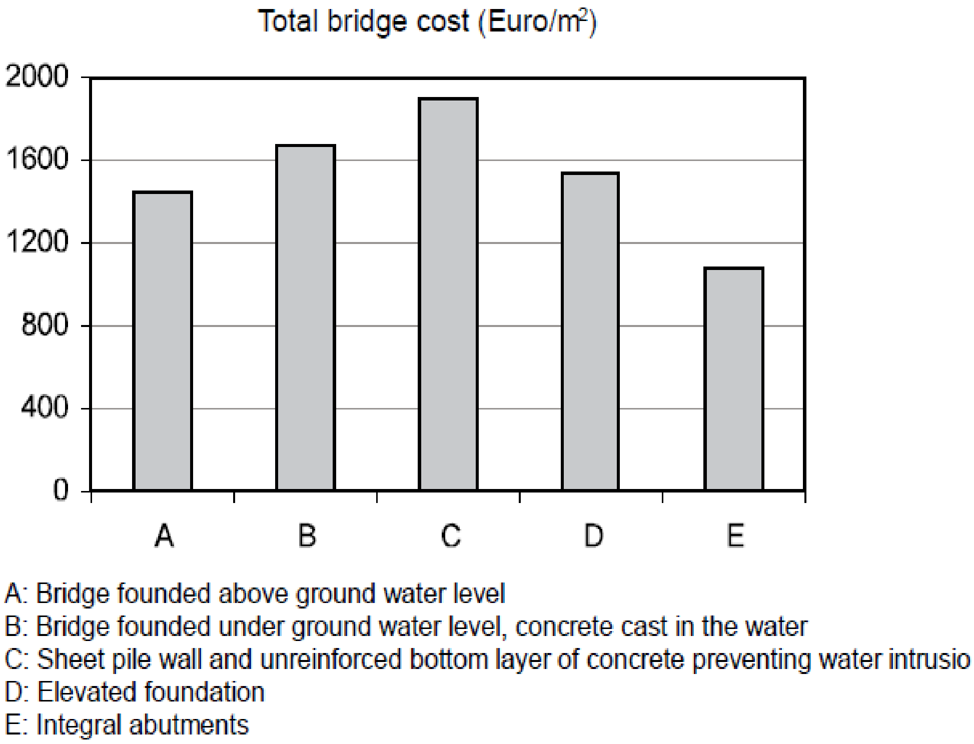

Figure 1.7 Comparison of bridge construction costs (Hans, 2015)

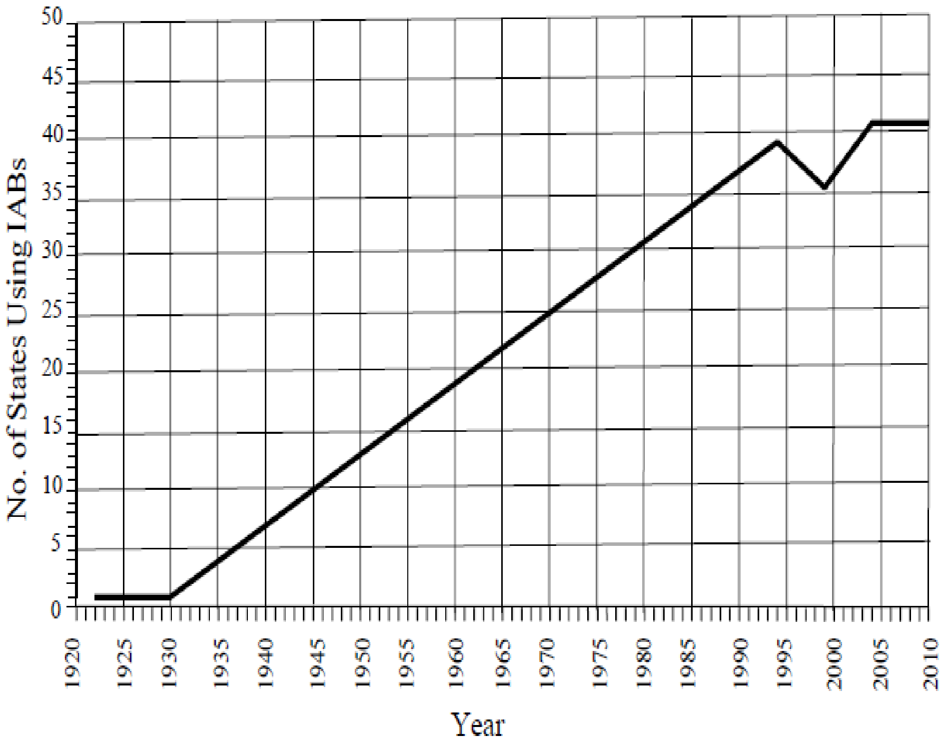

Figure 1.8 Rise of IABs in the United States (Paraschos and Amde, 2011)

Table 1.1: Number of IAJB designed and built since 1995 and in-service in U.S. (Rodolf and Samer, 2005).

	DESIGNED since 1995	BUILT since 1995	IN SERVICE (TOTAL)
Integral Abutment	~ 7000	~ 8900	~ 13000
Full Integral	~ 5700	~ 6400	~ 9000
Semi Integral	~ 1600	~ 1600	~ 4000
Deck Extension	~ 1100	~ 1100	~ 3900

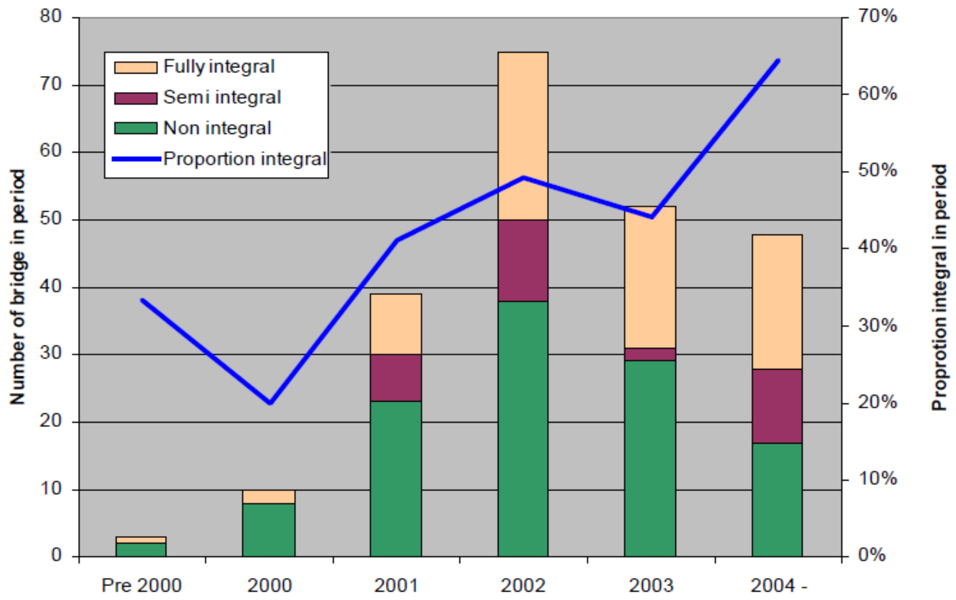

Figure 1.9 Summary of bridge type by dates in United Kingdom (David, 2006)

IABs have the following advantages over conventional bridges according to Arockiasamy et al., (2004); Hassiotis et al., (2006); Kunin and Alampalli (2000); Mistry (2005); Wasserman and Walker (1996); Ooi et al., (2010); Cheng (2012):

i. Lower construction and maintenance costs as a result of absence of construction joints and bearings.

ii. Serviceability and structural stability of the bridge is enhanced by the integral connection of girder to abutment. IABs have added redundancy and additional strength to withstand seismic loads during earthquakes.

iii. Integral connection between beam and abutment provides additional resistance to beams against uplift forces at end spans due to live loads.

iv. Smooth riding surface due to absence of joints reduces impact stress levels and improves riding quality.

v. Due to integral connection, the entire bridge behaves like a portal frame and is able to spread lateral loads to adjacent soil support thereby enhancing stability and reducing uneven settlement.

vi. Improved aesthetic feature of the bridge and enables rapid bridge construction.

vii. Rapid construction and bridge widening is achieved due to simplified features of IABs like fewer construction joints, uniformly spaced piles and so on.

In addition to the primary actions of live and dead loads, IABs being jointless bridges experience additional stress from temperature and time-dependent loadings such as creep, shrinkage, prestress cable relaxation and reaction from soil-structure interaction. Expansion and contraction of superstructure due to thermal loading, creep and shrinkage can result in flexural stress built up on piles supporting long span IABs. If the stress is large enough, it can lead to formation of plastic hinges and limit the flexural resistance of the piles to additional superstructure elongation (Burke, 2009). This nonlinear reaction which is severe during thermal expansion of the bridge can lead to translational and rotational displacement of the abutment wall. Soil structure interaction also affects the behaviour of IABs in relation to soil stiffness and foundation type (Faraji et al., 2001, George et al., 2002).

The behaviour of IABs is not adequately comprehended by bridge engineers despite the numerous applications of IABs in bridge constructions. Thermal, creep and shrinkage effects and soil-structure interactions have been the major source of concern in the ambiguities associated with the performance of IABs. Design and construction of IABs was therefore dependent on past experience as there is no design guide available in the existing codes of practice for IABs (Huang et al., 2008).

1.4 Problem Statement

In spite of IABs having functional and economic advantages over conventional bridges, there are many uncertainties regarding their behaviour that need to be fully understood. Most of these uncertainties arise as a result of elimination of movement joints leading to lateral movements occurring at bridge abutments. Removal of movement joints result in uncertainties relating to complexities in soil-structure interaction and nonlinear material behaviour. Bridge superstructures of IABs do experience cyclic expansion and contraction due to thermal load variation against passive resistance of backfill behind bridge abutment. In addition to this thermally induced superstructure and abutment displacement, nonlinear creep and shrinkage of bridge deck and girder create additional contraction of the superstructure and abutment against lateral resistance of piles supporting bridge abutment. Thermal movement, time-dependent response and soil structure-interaction makes the behaviour of IABs not fully understood (Huang et al., 2004; Ooi et al., 2010; Arockiasamy et al., 2004).

The absence of a unified design code that clearly defines the procedure for design of IABs is a point of concern that necessitates the need for further study on the behaviour of IABs. The practice of design and construction of IABs is mainly empirical in nature rather than systematic investigation (Arockiasamy and Sivakumar, 2005). There is no clearly defined analysis method and standardised design procedures in the current design specifications and guides; the behaviour is therefore unknown and the design is cumbersome resulting in low utilisation of IABs despite the enormous benefits (Kim and Laman, 2010a; Thippeswamy et al., 2002). There is therefore the need to further enrich our present limited understanding of behaviour of IABs under effects of temperature, creep and shrinkage.

1.5 Research Objectives

The behaviour of continuous prestressed concrete girder IABs under temperature and creep loads was studied in this research. This study has achieved the following objectives:

i) Developing a three dimensional finite element model that effectively predicts the effect of creep, shrinkage and thermal loadings on the performance of long spanning IABs.
ii) Quantifying the effect of creep and shrinkage on moment and shear capacities of prestress concrete girders of IAB.
iii) Proposing empirical model equations that can serve as guide in predicting long term response of IABs to creep loading. The equations should contribute to safe design of long span IABs beyond the current practice of limiting the span of IABs to 60 m.

1.5 Scope of Research

The research is conducted through numerical analyses using Finite Element Method. Modified Newton Raphson iteration method was used in nonlinear transient creep analyses of prestressed concrete slab on T beam IABs using CEB-FIP (1990) creep model for 75 years. The post tensioned IABs have no skew or curvature. Four IABs lengths were 60 m, 90 m, 120 m and 150 m with each bridge having pier to pier spans of 20 m, 30 m, 40 m and 50 m respectively. Linear Thermal analyses were conducted to study the response of the bridge to thermal loading in tropical climate. An average temperature range of 21^0C to 36^0C was chosen within the range of Malaysian climate (Malaysian Metrological Department, 2015) which was adopted as case study of the research. Soil behind bridge piles were varied form dense sand, medium dense sand, loose sand, stiff clay, medium stiff clay to soft clay to study the response of backfill and piles on bridge movement due to thermal and time-dependent loadings. Soil was modelled using linear springs and the spring stiffness was obtained with the use of force displacement curves (P-y curves).

1.6 Research Methodology

The Reseach was conducted through numerical analyses using finite element method and the analyses were carried out in finite element software LUSAS. Figure 1.10 provides flowchart of the step by step procedure followed in carrying out the reseach. Literature was reviewed and presented in Chapter two to establish research gap in previous studies on thermal and time-dependent behaviour performance of integral abutment bridge due to temperature, creep and shrinkage loadings. The research gap, as presented in Section 2.9 formed the research problem to be solved and the overall objective of the research. Structural design of IAB carried out using BS8110 (1997) code, was based on an existing IAB in Johor Bahru Malaysia. Three dimensional finite element models of IABs were developed to represent structural components of the bridge. Prestressing force was modelling using equivalent load method and the girder and the prestresssing tendon were modelled as single beam element. Soil-structure interaction for both backfill-abutment and soil-pile interaction were modelled using Clough and Duncan and p-y curve methods respectively. Nonlinear beam element with CEB-FIP 1990 code creep and shrinkage material properties was used to model prestressed concrete girders for the 75 years creep analyses. Linear beam elements were used to model girders for thermal loading. Models were tested by subjecting them to thermal and creep loadings in addition to live, dead and prestress loadings to obtain preliminary results which were validated using analytical procedure. Parametric analyses were carried out and the parameters considered are thermal load, creep and shrinkage, bridge length and stiffness of substructure soil.Loss in prestress loss, changes in creep coefficient, reduction in moment and shear capacities of prestress concrete girders of IABs were computed at the end of the analyses. Results of the analyses were used to develop empirical equations that can be used in long-term response prediction of IABs to creep loading. The equations were tested and validated to establish their accuracy and a conclusion was made on the usefulness of the equations in early predictive assessment of long-term performance of IABs to creep loading.

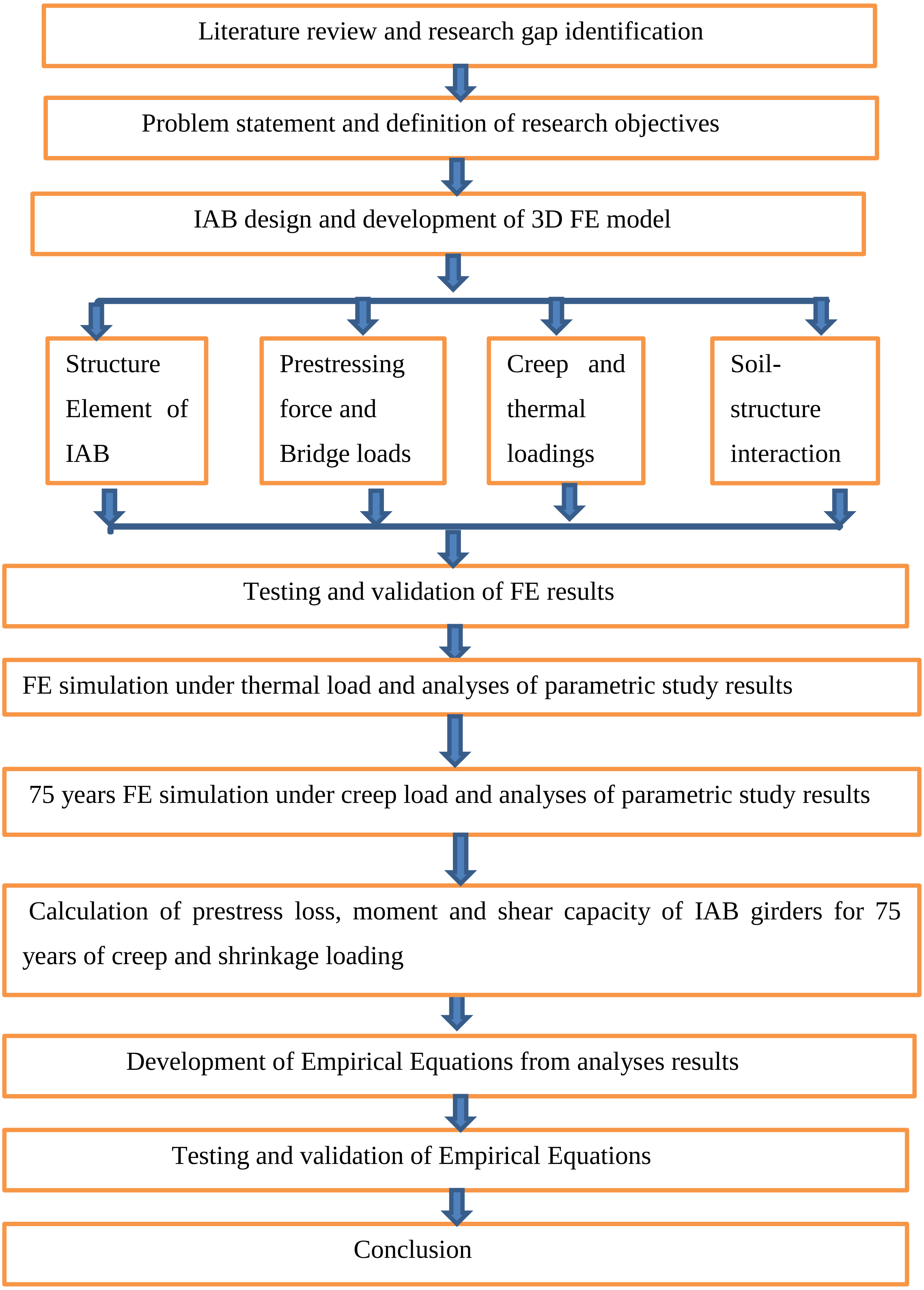

Figure 1.10 Flowchart of research methodology

1.7 Layout of Thesis

Chapter one presents the background of the research and explains the concept of IABs and their attributes. It also discussed limitations of IABS which formed the basis of the research problems, objectives, methodology and scope as discussed in the chapter.

Chapter two is a review on relevant literature to provide background knowledge of the research, prior research work conducted and what has not been adequtely covered by previous study which formed the basis of the present study. The topics covered include Concept and types of IAB, global approaches in its utilisation, secondary loading effects on the bridge, temperature and creep models and soil-structure interaction modelling.

Chapter three provides discussion on method used in finite element modelling of post-tensioned cable profile for continuous bridge girders and other structural elements of the bridge. Procedure followed in modelling soil-structure interaction for abutment-backfill interaction and pile-soil interactions under varying soil types were fully discussed. Results from finite element modelling were validated in this chapter.

Chapter four provided parametric study results for both creep and thermal loadings of IABs. The results of the analysis of 60 m 90 m, 120 m and 150 m, IABs are presented and explained. Empirical equations were developed, tested and validated.

Chapter five provides concluding aspects of the research. It discusses the research findings and achievements and provided general conclusion based on the research findings. It also provides recommendations for further studies on IABs.

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